Soil and Water Indicators of the Sustainable Rangelands Roundtable

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Abstract—*The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion, a category of conditions or processes that can be assessed nationally to determine if the current level of rangeland management will ensure sustainability. Within the soil/water criterion, 10 indicators, 5 soil-based and 5 water-based, were developed through the expert opinions of rangeland scientists, rangeland management agency personnel, non-governmental organization representatives, practitioners, and other interested stakeholders. Out of these 10, 5 were judged by the soil/water criterion group members as being most expedient for a future national level U.S.A. report on rangeland sustainability. The soil and water indicators are not inclusive, but provide a suite of variables, that when complemented with indicators from the 4 other criteria of SRR, produce a viable system to monitor at the national level the biophysical, social, and economic characteristics indicating trends of sustainability on rangelands.*

Introduction

Soil and water are essential for ecosystem processes. Primary production of ecosystems requires soils in terrestrial systems and water bodies in aquatic systems to support energy capture through photosynthesis and energy flow through consumption, growth, and respiration. Terrestrial nutrient cycling generally requires soil before nutrient uptake can occur in plants whereas aquatic nutrient cycling requires physical or temperature-induced mixing of nutrients within the water. In terrestrial systems, soil influences hydrologic processes by the capture, storage, and release of water (Whisenant 1999), but water and wind can erode soil. Soil erosion is regarded as a major contributor to declines in human civilizations over the past 7,000 years (Lowdermilk 1953). Rangelands and their associated communities rely on conservation and maintenance of soil and water resources to maintain them over time.

The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion, a category of conditions or processes that can be assessed to determine if the current level of rangeland management will ensure sustainability. As a criterion, conservation and maintenance of soil and water resources is too general to monitor directly, but it can be characterized by a set of indicators monitored over time to detect change.

Indicators are quantitative or qualitative variables that are assessed in relation to a criterion. An indicator describes attributes of the criterion in an objective, verifiable, and unambiguous manner, and is capable of being estimated periodically to detect change.

The indicators for the conservation of soil and water resources are divided between soil-related and water-related components of this criterion (table 1). The indicators are the outcome of an evaluation of the conservation and maintenance of soil and water resources indicators identified in the Roundtable on Sustainable Forests (RSF), soil and water resources indicators from Heinz (2002), plus our identification of new indicators that relate specifically to rangeland sustainability. Neary and others (2000), in an effort not associated with the Sustainable Rangelands Roundtable, evaluated the applicability to rangeland sustainability of the eight RSF soil and water indicators. We evaluated Neary and others (2000) and based on this evaluation we retained four of the RSF soil and water indicators (table 1).

We applied a standard set of questions to each indicator. The questions focus on: (1) what is the indicator, (2) what the indicator measures and why it is important to rangeland sustainability, (3) geographic variation of the indicator, (4) the meaning of the indicator at various spatial and temporal scales, (5) the availability, and quality of data sets, and (6) the degree of understanding that stakeholders have for the indicator. Here we provide answers to these questions for five of the 10 indicators. These five indicators are ones the soil/water group members judged to be most expedient for future national-level reports on rangeland sustainability.

Table 1. Indicators for soil and water conservation on rangelands, in no particular order of importance.

Indicators	What the Indicator Describes
Soil-based	
Area and Percent of Rangeland with Significantly Diminished Soil Organic Matter and/or High Carbon:Nitrogen (C:N) Ratio[a]	Soil productivity, infiltration, nutrient content, nutrient availability, nutrient cycling, carbon sequestration, resistance to erosion
Area and Extent of Rangelands with Changes in Soil Aggregate Stability[b]	Resistance to erosion by water and wind, soil water availability, root growth
Assessment of Microbial Activity in Rangeland Soils[b]	Soil productivity, decomposition, nutrient content, nutrient availability
Area and Percent of Rangeland with a Significant Change in Extent of Bare Ground[b]	Erosion potential, aboveground vascular plant productivity
Area and Percent of Rangeland with Accelerated Soil Erosion by Water and Wind[a]	Soil loss by water or wind, soil productivity
Water-based	
Percent of Water Bodies in Rangeland Areas with Significant Changes in Natural Biotic Assemblage Composition[a]	Water quality and aquatic habitat conditions
Percent of Surface Water on Rangeland Areas with Unacceptable Levels of Chemical, Physical, and Biological Properties[a]	Water quality
Changes in Groundwater Systems[b]	Water quantity, watershed functioning, change in geographic extent of riparian and wetland ecosystems
Changes in the Frequency and Duration of Surface No-Flow Periods in Rangeland Streams[c]	Aquatic and terrestrial biodiversity, watershed functioning
Percent Stream Miles in Rangeland Catchments in which Stream Channel Geometry Significantly Deviates from the Natural Channel Geometry[b]	Watershed functioning, including sediment transport, sediment filtering and retention, substrate composition, flood amelioration, fish and wildlife habitat, aquifer recharge, water temperature, and season and duration of surface flow

[a] Originated with Roundtable on Sustainable Forests and was retained in SRR.
[b] A new indicator identified by SRR.
[c] Originated with Heinz (2002) and was retained in SRR

Area and Percent of Rangeland With Significantly Diminished Soil Organic Matter and/or High Carbon:Nitrogen (C:N) Ratio

Importance of the Indicator

This indicator measures the soil organic carbon (soil organic matter) content of the soil, and the carbon:nitrogen (C:N) ratio of the soil organic matter. The C:N ratio is a relative measure of soil organic matter's potential for biological decomposition. Soil organic matter provides many benefits to the soil and is associated with the productive potential of soils and soil sustainability. The C:N ratio of soil organic matter provides an indication of the potential availability of the organic matter to microbial decomposition, and therefore, nutrient release for plant growth. Soils with a high C:N ratio would indicate that the organic matter is more resistant to biological decomposition whereas soils with a C:N ratio of < 10:1 would indicate a good healthy soil and one that would have good biological decomposition of organic matter occurring.

Geographic Variation and Scale in Time and Space

Soil organic matter levels vary by soil type, plant community, and climate. Fine-textured soils with greater clay content generally exhibit greater soil organic matter levels, because the productivity potential is greater, attributable to the greater water holding capacity and reduced decomposition and oxidation rates in fine-textured soils (Reeder and others 1998). Changes in vegetation and litter inputs, for example as a result of a significant shift from C3 grass-dominated plant communities to C4 grass-dominated plant communities, result in greater root:shoot ratios and greater C:N ratios (Schuman and others 1999). Climate and its effects on soil moisture and temperature affects rangeland productivity, which directly influences soil organic matter levels. For example, tallgrass prairie will have greater soil organic matter levels compared with shortgrass prairie because of the greater contributions of litter and root biomass attributable to the greater productivity. Climate also affects decomposition rates, which influences soil organic matter levels.

Soil organic matter and its C:N ratio also can reflect temporal changes attributable to changes in management. Although temporal changes in soil organic matter and C:N ratios lag somewhat to temporal changes in vegetation and litter, the changes can be detected in enough time to initiate management changes to prevent serious degradation of soil. Spatially, soil organic matter varies considerably, reflecting the heterogeneity of soils across short distances. The degree of heterogeneity across short distances infers difficulty in sampling rangelands adequately for a national-level assessment of soil organic matter; however, baseline-sampling sites can be established to compare and detect change over time and space.

Data Collection and Availability

Methods of assessing soil organic matter and C:N ratios are available and are adaptable to the regional and national level. Soil organic matter is generally reported as soil organic carbon, rather than vice-versa. It is recommended that soil organic carbon be assessed to detect spatial and temporal changes in soil organic matter. The laboratory methodologies available for measuring soil organic carbon are economical, repeatable, and accurate but to date, no in situ field methodology exists for assessing soil organic carbon. Whereas a great deal of soil organic carbon data exist that can be used to make initial assessments, C:N ratio data are not as prevalent because simultaneous nitrogen data were not always collected in earlier studies. Recently, researchers have begun to collect soil organic carbon and nitrogen, because of the heightened recognition of the interrelationships of carbon and nitrogen from a microbial and nutrient cycling standpoint. Also many laboratories are now using combustion methods for determination of soil organic carbon which routinely includes nitrogen analyses. In general, soil organic carbon and nitrogen data are limited for rangelands compared with croplands.

Clarity to Stakeholders

Stakeholders generally understand the importance of organic matter as it relates to soil. However, soil organic carbon and the C:N ratio are less well understood, particularly how they relate to litter decomposition and nutrient cycling.

Area and Percent of Rangeland With a Significant Change in Extent of Bare Ground

Importance of the Indicator

Bare ground is exposed mineral or organic soil that is susceptible to raindrop splash erosion (Morgan 1986). Increases in bare ground and greater homogeneity of existing bare ground relate—directly—to a site's susceptibility to accelerated wind or water erosion (Benkobi and others 1993, Blackburn and Pierson 1994, Cerda 1999, Gutierrez and Hernandez 1996, Morgan 1986, Pierson and others 1994, Smith and Wischmeier 1962). The importance of bare ground as an indicator is a function of: 1) its direct relationship to erosion risk; 2) its known value as an indicator of changes in land management and watershed function (Branson and others 1972); and 3) the ease and economy with which this indicator can be monitored over extensive areas, particularly when using remote sensing methods (Abel and Stocking 1987, Booth and Tueller 2003, Tueller and Booth 1975). It also lends itself, more than most other natural resource indicators, to automated measurement by computer image-analysis techniques (Bennett and others 2000, Booth and others 2003).

Geographic Variation

The amount and distribution of bare ground varies. On many rangelands, little bare ground exists because litter, rock, gravel, and sometimes functional biological soil crusts, cover the non-vegetated areas. Bare ground also varies among: 1) soils of differing parent materials, texture, and age; 2) plant communities; 3) lands with differing precipitation patterns; and 4) grazing intensities—to name some of the more prominent variables.

Bare ground is a meaningful indicator in all different regions when compared by site over time so that the natural range of variation is established. Soil series or ecological site descriptions (http://esis.sc.egov.usda.gov/, accessed 09/02/2004) might become useful for predicting bare ground; however, that use must be preceded by years of trend-analysis data collection and correlation of bare ground with the relevant variables such as climate, aspect, vegetation (existing and historical), geology, and slope.

Scale in Time and Space

Until the stability and range of variation of a given ecosystem or management unit is established, it seems advisable to measure bare ground frequently (1 to 5 year intervals). Where the natural range of variation is established and data indicate bare ground is relatively stable over time, a 5 to 10-year sampling interval seems appropriate unless there is a significant disturbance or change in management. Methods of measuring bare ground include point, plot (area), and linear (line intercept) methods. Point methods include the point frame (Levey 1927), and the point-step (Evans and Love 1957). Plot methods include the now archaic charting (usually of a 1-m^2 plot) by means of a pantograph (Stoddart and Smith 1955) and 2-cm diameter Parker loop (Parker 1951).

Bare ground measurement by image analysis has developed considerably since Cooper (1924) described his methods for obtaining vertical photographs of vegetation from 1.8 m above ground level. Daubenmire (1968) observed that cover could be measured from an image (chart, map, or photograph) by using a planimeter, by cutting out and weighing parts of the image, or by using a dot grid. Computers greatly facilitate cover measurements from images. Where image pixel resolution is similar to the 2 mm per pixel used by Bennett and others (2000), image analysis can be considered a direct, point-sampling of ground-cover that gives greater precision than is obtained by on-the-ground methods like the point frame (Bennett and others 2000, Walker 1970, Wells 1971). Images with less resolution give an area measurement. Point sampling (dot grid or pixel count) used with lower-resolution images measures image cover (as opposed to ground cover) and image cover converts to a ground-area measurement. The greater the ground area per pixel, the greater the inaccuracies attributable to pixels containing mixtures of bare ground and other attributes (for example, vegetation, rock, gravel, litter, and biological soil crusts). These are inaccuracies of absolute bare ground per unit area. The inaccuracies are less problematic if we consider only temporal changes by delineating the exact area and using the same method to measure change over time. Regardless of methods, season and annual variation in vegetation cover may impact the measure of bare ground and must be considered when interpreting changes (Anderson 1974, Gutierrez and Hernandez 1996).

As with all indicators, data collected at a local level are not easily extrapolated to, and reported over, larger geographic areas without a sampling design consistent with the inherent variability of the larger geographic area being monitored. It is usually impractical for extensive land areas such as public grazing allotments or watersheds to be monitored using sample numbers and a distribution adequate to something like a 95% confidence interval if sampling is limited to ground-based methods. Aerial sampling as used by Abel and Stocking (1987), Booth (1974), and Booth and others (2003) greatly enhances the practicality for adequate sampling over extensive areas.

Data Collection and Availability

Some data set(s) exist at the regional to national level, but methods and procedures are not standardized at the regional to national level. For most available data, bare ground was not measured using the strict definition we used above (for example, the National Resource Inventory began using our strict definition in 2003 for rangeland surveys, Pyke and others (2002), Spaeth and others (2003)). The data sets exist as 2 types, ground data collected with various methods, and remotely sensed data.

Ground data: Bare ground is included in vegetation analyses for many agencies and non-governmental organizations, including most military reservations in the United States (for example, the military's Land Condition and Trend Analysis). The data within and among these agencies and organizations have been collected using various methods and for numerous sites yet lack adequate sampling designs for regional to national aggregation. However, where sequential, comparable data exist, they may provide a useful measure of the natural range of variation for the site. Another potential source for obtaining the natural range of variation for bare ground is the USDA-NRCS, individual soil pedon data for recent surveys. The aggregated data for soil map units and taxonomic units are stored in NASIS (National Soil Information System) and available through the SSURGO (Soil Survey Geographic) database for digitized surveys. A limitation here is that ground cover is probably ancillary data in most soil surveys, without stringent standards for providing estimates (C. Talbot 2003, pers. comm.).

Remote sensing data: Data sets (U.S.A. or otherwise) with an image resolution that potentially allows an accurate measure of bare ground (Morgan 1986) are rare and largely limited to research efforts (Bennett and others 2000, table 1 in Booth and Tueller 2003, Booth and others 2003, Wells 1971). No remote sensing study has measured bare ground classification accuracy using the strict definition adopted from Morgan (1986). Theoretically, bare ground can be measured using existing remote sensing data bases but measurement inaccuracies are likely, attributable to pixels containing mixtures of factors and to variable amounts of soil moisture and organic matter that confound image analysis. Research is addressing these limitations.

The brightness, or intensity, of radiation reflected from bare ground is high because there is nothing to absorb it. Conversely, a dense vegetation cover absorbs most of the incoming red radiation, so its brightness is low. The light that vegetation does not absorb well is the infrared wavelengths; therefore, heavily vegetated areas reflect a high proportion of infrared light. The combination of low red and high infrared reflectance is often referred to as "greenness." Most remote sensing studies categorize areas as bare ground in an indirect manner, by assuming that areas not reflecting infrared must be non-vegetated. This is somewhat simplistic however because of the confounding classification factors mentioned previously, and the fact that many arid land plants exhibit little spectral greenness. However, the results of such studies do describe increases in bare ground associated with land degradation.

A number of remote sensing studies have shown a high accuracy for a bare ground category when classifying images at various scales (Tueller and Oleson 1989, Tueller and others 1988), however, these studies do not adhere to our strict definition for bare ground, nor do they partition out the confounding factors mentioned previously. For arid rangelands, areas of bare ground can be identified with high accuracy using representative fraction scales varying from 0.2 m pixel Kodak Color infrared digital air photo data, to 0.6 m Quick Bird (commercial satellite system) data, to 1 m IKONOS (commercial satellite system provided by Space Imaging, Inc., Thornton, Colo.) data, to 5 m pixel IRS satellite data. Changes can be quantified easily where areas are classified and the bare ground category is reasonably accurate based on image processing techniques. Resolution of these confounding classification factors at various scales will enhance the usefulness of remote sensing for quantifying bare ground and monitoring bare ground changes on rangelands.

Recently, remote sensing experts have been experimenting with hyperspectral data. Hyperspectral systems provide complete spectroradiometric curves of various sized polygons, representing individual plants or plant communities (vegetation types) depending on the scale. Spectroradiometric curves show discrete absorption features that can represent bare ground, individual soils, or the mineral characteristics of specific kinds of soils. The shape of spectroradiometric curves can be indicative of the amount of bare ground in a pixel. Research in this field is promising and should be encouraged. In addition, new IFSAR (Interferometric Synthetic Aperture Radar) systems may provide new data that will be useful to evaluate bare ground.

Ground vs. remote sensing: West (1999) stated, "I see no hope that traditional methods of monitoring, via point sampling on the ground (italics added), will be able to accomplish those (monitoring) needs…especially when landscape and regional perspectives are required. There are simply not enough adequately trained people and that approach would not be affordable, even if the necessary professionals existed." This was demonstrated by the National Resource Inventory, Colorado Test (a prototype procedure) where random sampling and ground data (objective and subjective) collection was used (Pellant and others 1999). Pellant and others (1999) reported an average 2.5 hours travel time for 3-person teams to reach sample sites. This included the use of helicopters for sites not accessible to wheeled vehicles. Field data collection cost (with no data analysis included) was $893 per sampled site. The field crews sampled 448 locations at a total cost of $400,000 (Pellant and others 1999).

The dilemma has been in choosing where to error. The smaller the scale (larger sized pixels) used in remote sensing the greater the extensive information about large-sized geographic areas, but the lower the accuracy of our inference about specific details (that is, the area of land susceptible to raindrop splash). Conversely, accurate measurement of bare ground at specific sites limits the geographic area of inference and has high cost and increasingly difficult access for ground work. Hopefully, the newly evolving technologies will solve the dilemma.

Clarity to Stakeholders

The public generally understands that bare ground is less desirable than soils covered by vegetation. Changes in the extent of bare ground over time, rather than how much bare ground there is at any moment in time, are more compelling in regard to rangeland sustainability. The concept of some bare ground being normal for many rangelands, rather than all bare ground being viewed as negative, is a concept that stakeholders still need to understand.

Area and Percent of Rangeland With Accelerated Soil Erosion by Water and Wind

Importance of the Indicator

Soil erosion by wind or water begins with the loss of all or part of the surface horizon. Surface horizons of soils are important to maintain because they contain the majority of the organic material and are the exchange medium for transferring nutrients from the soil to plants. Losses of soil through erosion may lead to reductions in the productivity of the site (Davenport and others 1998, Dormaar and Willms 1998). Upper soil horizons typically contain the highest organic matter and nutrient content therefore this component of the soil generally controls the rate of water infiltration, plant establishment, and growth (Wood and others 1982). Excessive erosion can contribute soil sediments to waterways thereby reducing water quality.

Since 1945, UNEP (1990) estimates that 11% of Earth's vegetated soils (1.2 billion ha) have become degraded to the point that their original biotic functions were damaged and that reclamation would be impossible or too costly. Wind and water erosion caused most of this degradation. Accelerated erosion is arguably the number 1 contributor to declines in human civilizations over the last 7,000 years (Lowdermilk 1953), which points to the importance of monitoring soil erosion rates as an indicator of rangeland sustainability and the sustainability of human civilizations associated with rangelands.

This indicator will identify areas where erosion is greater than expected for the soils on a specified site. It is not to identify areas with high natural erosion rates (for example, the South Dakota Badlands in U.S.A.). This indicator measures soil loss by the action of water or wind.

Geographic Variation

Soil erosion on rangelands was recognized as a serious problem at both local and national levels in the U.S.A. in the 1920's (Weltz and others 1998). Soil erosion varies by soil and by plant community but is important in any region. Local, regional, and national data on soil erosion can only be accumulated if similar soils and vegetation are affected and the data summarized for the total of the affected areas.

Scale in Time and Space

This indicator is applicable at various spatial and temporal scales. Its applicability depends on the kind of soil involved and the ability to measure rills and gullies, provide evidence of interrill erosion, and measure soil movement through the air. Rill erosion is caused by concentrated runoff water flowing over the soil, whereas interrill (sheet) erosion results from raindrop impact and splash. Soil aggregate size and stability, biological soil crusts, physical crusting, random and oriented roughness, and extent of vegetative cover are related to wind and water erosion. The distribution of these erosion characteristics and their changes across spatial scales from an individual plot to large geographic areas will influence changes in erosion. The temporal scale would be in terms of years but often related to individual storm events in relationship to overgrazing and other sources of rangeland degradation.

Data Collection and Availability

Accelerated erosion by water can be observed using several parameters including movement of litter downslope, evidence of sheet erosion, or an increase in the number and size of rills and gullies (Pellant and others 2000). Soil erosion rate can be viewed as a function of site erosion potential (SEP) determined by climate, slope conditions, soil erodibility, and ground cover. In pinyon-juniper dominated areas with high SEP, the erosion rate is highly sensitive to ground cover and can cross a threshold so that erosion increases dramatically in response to a small decrease in cover (Davenport and others 1998). After disturbance, both runoff and erosion amounts tend to increase and remain at elevated levels for a decade or more although the rate is not increased with time (Wilcox and others 2003). As rangeland vegetation mosaics change resulting from disturbance, ecologically important changes in runoff and erosion can result (Reid and others 1999).

Wind erosion and transport of surface materials depends on the strength of the wind, the soil surface texture, and the surface protection materials including rocks, biological soil crusts, and vegetation. Surface soil texture is an important key to wind erosion hazard potential. Loamy sand and sand are the most vulnerable soil textures to wind erosion. Clayey soil, because of the ultrafine particle size with highly reactive surfaces, has better structure, and hence is more resistant to wind erosion. Coarse sand and gravelly or rocky soils also are more resistant to wind erosion, because the particles are too heavy to be removed. Wind erosion can lessen soil productivity because wind erosion physically removes soil particles and organic matter near and at the soil surface, and because soil fertility (for example, nitrogen and phosphorus) decreases with decreases in organic matter content (Foth 1984). Soil particles can enter suspension and become part of the atmospheric dust load. Dust obscures visibility, pollutes air, and fills road ditches and the result can be decreased water quality, automobile accidents, fouling of machinery, and imperilment of animal and human health (Skidmore and Layton 1988). Accelerated erosion constitutes a very strong indicator of rangeland degradation.

Standardized methods and procedures for data collection and reporting have been studied for use at the regional to national level, but useable data set(s) do not exist at the regional to national level. However, on natural rangelands the Universal Soil Loss Equation (USLE), Revised USLE (RUSLE), RUSLE2 and Water Erosion Prediction Project (WEPP) have been or are being evaluated for rangeland use. Early models (USLE and RUSLE) were developed for cropland and failed as useful predictors of erosion on rangelands. NRCS soil survey data potentially can provide a national level soil erodibility and soil erosion data set on rangelands, but erosion was a visual estimate of an observer at an NRI point while erodibility was calculated using the inaccurate USLE or RUSLE models.

Remote-sensing techniques provide a promising technology to obtain information on soil erosion, but limited testing has been done. We encourage additional research to refine and test various methods for obtaining accurate data over larger areas.

Clarity to Stakeholders

Stakeholders understand erosion. When interested individuals see active or past erosion the reaction is often a concern for the health of the land. More subtle signs of erosion and the concept of wind-caused dust and the relationship of these to good land stewardship is obscure, requiring further stakeholder tutoring over time.

Percent of Surface Water on Rangeland Areas With Unacceptable Levels of Chemical, Physical, and Biological Properties

Importance of the Indicator

This indicator measures the percent of surface water with impaired water quality. Surface water includes the length of small, medium, and large streams and rivers, and the area of lakes and reservoirs. Under the Clean Water Act, states and authorized tribes develop water quality standards for their individual stream and river segments, often including their lakes and reservoirs (U.S. EPA 1994). A water body segment is a bounded part of a stream, river, lake, or reservoir that is regulated by a set of water quality standards. To establish these standards, states and tribes identify designated beneficial uses (for example, drinking water, recreational, agricultural) for each of their water segments, and then set water quality criteria to ensure protection of its chemical, physical, and biological integrity (U.S. EPA 1994). A water quality criterion is an ambient concentration of an important parameter (for example, dissolved oxygen, or pH, or temperature, or heavy metals; usually a LD50 or other metric) that ensures that the designated use or uses for a given water segment are not impaired. Impaired water quality means that 1 or more of the criteria adopted to protect the designated use or uses of an individual water body segment are not being met. Leading causes of water quality impairment of our nation's waters are excess nutrients (nitrogen and phosphorus), sediment/siltation, pathogens, and metals (USDI-USGS 1999). EPA's National Water Quality Inventory 2000 Report states that approximately 40% of the nation's assessed streams are impaired (http://www.epa.gov/305b/, accessed 09/02/2004). Water resources must be of adequate quality to support a variety of uses such as human and livestock consumption, wildlife habitat, agricultural and industrial supply, and recreation (Heinz 2002). Water quality is important to rangeland sustainability because wildlife, recreation, livestock, downstream water users, and others depend on clean water, particularly in arid and semi-arid rangelands.

Geographic Variation

Water quality standards will vary geographically. For a particular water body, the water quality parameters which are deemed important, and the appropriate criteria or thresholds, will depend on the designated uses. In addition, states and tribes consider natural ranges of variation when designating uses and developing water quality standards. Water quality impairment assessments are local decisions because our nation's waters do not naturally exhibit the same characteristics, for example the ability to support a cold-water fishery. However, states and tribes regularly monitor and assess water quality, and identify their water bodies that do not meet their standards. These impaired water bodies are reported on a Clean Water Act Section 303(d) list that is updated biennially (US EPA 2003).

Scale in Time and Space

States and tribes have flexibility on how they determine designated uses, what water quality parameters to monitor, what monitoring methods to use, and what methods are used to assess water quality. Also, to meet management and compliance objectives, most water quality monitoring is conducted at "fixed" stations, and the resultant data are not necessarily representative of the whole water body or watershed. National reports on water quality do not yet provide an assessment of all the watersheds in the United States. For these reasons, scaling water quality parameter data up to a regional or national reporting level would be very difficult, as would be assessing comprehensive regional or national trends of important water quality parameters. However, the Section 303(d) impairment lists, updated by the states and tribes using the local water quality data, provide information nationally of deteriorated water quality and its causes (US EPA 2003). Reporting of Section 303(d) lists began in 1998, and the states are required to update their lists every 2 years. As part of their Section 305(b) requirements, States have for the last 30 years been monitoring and reporting water quality information into EPA's national data system, STORET (not a true acronym, stands for Water Quality Storage and Retrieval System).

Data Collection and Availability

Under Section 305(b) of the Clean Water Act, EPA, other federal agencies, states and tribes are to monitor their waters for water quality, and report that information in STORET. Additionally, a National Water Quality Inventory is required biennially, which is a report that summarizes water quality reports submitted by states, territories, interstate commissions, and tribes. For reasons stated previously, this report cannot be used as a regional or national assessment, or for national trends in water quality. Also required is a biennial Section 303(d) list of impaired waters (US EPA 2003). These impaired waters are required to develop a TMDL (total maximum daily load). TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. This is probably the best information we have on impaired water quality, and initially should be the data sources for this water quality indicator.

Another potentially useful data source is the USGS (United States Geological Survey) National Water Quality Assessment (NAWQA) program. To help support local decision makers in developing TMDLs and to provide long-term, nationwide information on water quality, NAWQA is starting its second decade of intensive water quality assessments. These assessments will cover 42 large hydrologic systems representing about 60% of the nation's waters used for drinking and irrigation, and include a broad list of physical, chemical, and biological measures including stream flow and stream habitat, water, sediment, and tissue chemistry, and characterization of algae, invertebrate, and fish communities. However, NAWQA data coverage on rangelands is limited, because at least half of the 40% non-coverage area is rangeland.

Clarity to Stakeholders

The concept of a water body meeting or not meeting a water quality standard is an easily understood concept to stakeholders.

Changes in the Frequency and Duration of Surface No-Flow Periods in Rangeland Streams

Importance of the Indicator

This indicator is patterned on an indicator developed by The Heinz Center (Heinz 2002). This indicator annually measures: 1) the percentage of rangeland streams with at least 1 day of no flow (also referred to as zero flow) in a year; and 2) for stream gauging stations showing at least 1 day of zero flow, the duration of zero flow events compared with a long-term average. Together, these 2 variables describe the frequency and duration of surface no-flow periods. There are numerous reasons for why streamflow is important in sustaining environmental, biological, social, and economic systems, not the least of which are: 1) the maintenance and recharge of ground water and the retention and productivity of streambank-stabilizing vegetation; 2) the continuity and quality of fish habitats; and 3) the availability of water for agricultural and municipal use and recreation.

Surface no-flow periods can occur naturally. Surface no-flow periods also can occur because of increased water use for domestic, irrigation, or other purposes, or because of changes in land use (for example, transition from rangeland to urban), or because of changes in vegetation which modify the flow of surface water and the recharge of groundwater (for example, expansion of deep-rooted vegetation such as pinyon or juniper, which can draw down surface aquifers). Changes in surface no-flow periods also can be attributable to changes in weather and/or climate.

Geographic Variation

This indicator has been reported at the division level of Bailey's ecoregions (for example, 250—prairie division; 260—Mediterranean division [Bailey 1995, in Heinz 2002]), and in the temporal range from 1949-1999 based on USGS stream gauge data, http://nwis.waterdata.usgs.gov/usa/nwis/discharge, accessed 09/02/2004, in Heinz (2002). Differences are discernible over time at the division level of Bailey's ecoregions, and spatially between divisions.

Scale in Time and Space

The indicator does not identify cause of increases or reductions in the frequency or duration of zero flow events, but is meaningful at the division level of Bailey's ecoregions and at decadal scales (Heinz 2002).

Data Collection and Availability

Methods and procedures for data collecting and reporting, and data sets of useable quality exist at the regional to national level, and are maintained by USGS and are available at http://nwis.waterdata.usgs.gov/usa/nwis/discharge.

Clarity to Stakeholders

Stakeholders can understand that changing streams from perennial to ephemeral or intermittent will impact the aquatic organisms that cannot tolerate periods without flowing water, but we anticipate they do not understand the relationships between periods of no-flow and groundwater levels.

A Look Ahead

Several of the indicators pose challenges regarding their applicability over broad geographic areas. Sampling schemes have not yet been designed for some of the indicators to achieve an objective of regional to national-level reporting of change over time. Some indicators are esoteric and would need effort to increase their understanding among stakeholders before they would be widely accepted as being credible.

We are discovering that regional and national level data sets are not available for most of the indicators; data sets often are more available for smaller geographic areas, with various methods used for measurement. Elaborating on the quality of data sets has been challenging because quality-control information is scant in the literature.

The 5 indicators presented here represent the "keystone" indicators from the Soil/Water Criterion Group that will likely be of focus in a proposed interagency (Bureau of Land Management, Forest Service, and Natural Resources Conservation Service) sustainable rangelands report scheduled for completion by 2010. Soil and water are the basic resources of rangeland sustainability. The identification and eventual quantification of rangeland indicators related to soil and water might provide an approximation of rangeland sustainability for our nation and provide a blueprint for evaluating rangeland sustainability worldwide.

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